IMPROVING SAFETY FOR RITI COMMUNITIES IN IDAHO

Documenting Crash Rates and Possible Intervention Measures

FINAL PROJECT REPORT

by

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16. Abstract

This report describes a new set of Geographic Information System (GIS) tools that we created to conduct safety analyses. These new GIS tools can be used by state DOTs and transportation agencies to document crash rates and prioritize safety improvement projects. The tools perform Network Segment Screening, the first step in the Roadway Safety Management Process (RSMP) outlined in the Highway Safety Manual (HSM). After developing these new tools, we conducted two case studies to demonstrate how they can be used. The first case study was for screening intersections. Our analysis included all intersections on the Idaho State Highway System. In practice, the analysis would likely be done only for a subset of intersections, such as only for signalized intersections on urban arterials. We chose all intersections for illustration purposes. The result was a ranking of intersections that would most likely benefit from safety improvement efforts. We applied three performance measures to rank the intersections: Crash Frequency, Crash Rate, and Equivalent Cost. The second case study was for screening roadway segments. Again, the entire Idaho State Highway System was included for illustration. The HSM describes two key methods for screening roadway segments: Simple Ranking and Sliding Window. Both methods are available in the new tools. This case study demonstrates the advantage of the Sliding Window, which would be impractical to accomplish on a large scale without the assistance of our new GIS tools. The final part of the work presented in this report is a synthesis to identify and document possible measures to reduce crashes for RITI communities in Idaho and throughout the northwest region.

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SI* (MODERN METRIC) CONVERSION FACTORS

Symbol	When You Know	Multiply By	To Find	Symbol
APPROXIMATE CONVERSIONS TO SI UNITS				
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

This report describes a new set of Geographic Information System (GIS) tools created to conduct safety analyses. These new GIS tools can be used by state DOTs to document crash data and prioritize safety improvement projects. The tools perform Network Screening and segment screening and are the first step in the Roadway Safety Management Process (RSMP) outlined in the Highway Safety Manual (HSM). Our tools are based on procedures described in the Highway Safety Manual (HSM), which was published by the American Association of State Highway and Transportation Officials (AASHTO) in 2010.

The HSM is a four-volume compendium of calculations and methods that can be used to prioritize roadway segments and intersections for safety improvement (AASHTO, 2010). In 2014, AASHTO released a software package called “Safety Analyst” based on the HSM procedures. State DOTs could license the software for approximately $20,000 per year. This software, however, has not been popular and will be discontinued on June 30, 2022 (AASHTO, 2019). It has been criticized for being overly complicated to use while at the same time lacking in capability. Furthermore, AASHTO’s software has limited integration with GIS. The tools developed for this project are easy to use and highly integrated with GIS.

After developing the tools, we conducted two case studies to demonstrate how they can be used. The first case study demonstrates how our new system of tools can be used for Network Screening and the second case study demonstrates how it can be used to screen segments. The tools create useful maps to show spatial patterns. The tools should be used within the larger context of the Roadway Safety Management Process to reduce the number of crashes as well as their severity. While ranking results can vary between performance measures, they often identify similar intersections that could benefit from improvements.

The final part of the work conducted as part of this project is a synthesis to identify and document possible measures to reduce crashes for RITI communities in Idaho and throughout the northwest region.

CHAPTER 1. INTRODUCTION

1.1. Overview - Project Scope and Objectives

This project is a continuation of a CSET Year-1 project at the University of Idaho titled "Documenting the Characteristics of Traffic Crashes for RITI Communities in Idaho". It represents the second step in establishing an in-depth understanding of the traffic safety conditions in Rural, Isolated, Tribal, and Indigenous (RITI) communities toward the ultimate goal of improving safety for these underserved groups through research, education, and outreach activities.

The Year-1 project had three objectives: 1) identify and document different sources of crash data for RITI communities in Idaho, 2) conduct an in-depth crash analysis to document the characteristics of traffic crashes in RITI communities in Idaho, and 3) identify and document different sources for traffic exposure data (vehicle-miles-travelled) for RITI communities in Idaho (Abdel-Rahim 2020).

In this second project we aim to achieve the following three objectives:

- Develop a methodology to estimate Average Annual Daily Traffic (AADT) on rural roads based on available traffic counts and on "potential network flow" between origins and destinations;
- Use AADT and other exposure measure data to document crash rates for different roadway segments in RITI communities in Idaho; and
- Synthesize and document possible engineering, education, and outreach intervention measures to reduce the number and severity of crashes for RITI communities in Idaho.

The outcome of this project will help aid and guide the State of Idaho's efforts to improve safety on its RITI roadway network by identifying effective crash countermeasures that have the highest possible return on investment for these communities. They will also help USDOT, FHWA, and other entities that focus on improving safety on rural highways gain in-depth knowledge of the characteristics of traffic crashes in RITI and similar communities throughout the nation. Our work will also help identify gaps in crash data collection practices and policies for these communities as well as gaps in traffic exposure measures that can be used to effectively measure crash rates.

1.2. Research Approach and Methodology

The primary task in this research work is to develop a methodology to estimate Average Annual Daily Traffic (AADT) on RITI Road networks. In any risk assessment, the identification of how to represent exposure relative to the risk involved plays a critical part of a risk assessment comparative analysis. For crash rates on the roadway network that serves RITI communities, however, accurate estimation of vehicle-miles travelled may not always be available. In a previous study, we developed a new method to estimate AADT for residential roads, which also typically lack AADT data (Lowry and Dixon, 2012). Our innovative method estimates AADT based on "potential network flow" between origins and destinations. The origin points are obtained from the US Census Bureau and the destination points are obtained from Google Places (grocery stores, restaurants, schools, etc.). Potential network flow is then calculated by finding the shortest route between origin and destination points using an algorithm that accumulates the thousands of potential trips between every origin and every destination (and every origin to origin, destination to destination, etc.).

Next, the potential network flow is compared with observed AADT to determine a proportional relationship for the rest of the network. This case study had an out-of-sample R2 = 0.95, which is very good for AADT estimation (Lowry, 2014). As part of this project, we also investigated how to adapt our method to estimate AADT on rural roads.

The project created a new set of Geographic Information System (GIS) tools to conduct safety analyses. These tools are designed to be easy to use and to be highly integrated with GIS. The tools have been developed using the ArcGIS environment, however they can be integrated within any other GIS package. Two case studies were conducted using our new tools to demonstrate how they can be used to determine document and screen crash rates at intersections and at roadway segments. They also facilitate data storage, data exchange, and data management following guidelines in the CSET data management plan, and to conduct a time series analysis to explore the changes in crash risk and severity over time.

The tools should be used within the larger context of the Roadway Safety Management Process to reduce the number of crashes as well as their severity. Therefore, the final part of the work we conducted as part of this project is a synthesis to identify and document possible measures to reduce crashes for RITI communities in Idaho and throughout the northwest region.

1.3. Report Organization

This report is organized in six chapters. After the introduction, chapter 2 presents the details of the new safety analysis GIS-based tools. Chapter 3 and Chapter 4 present two cases studies that demonstrate the use of the developed tools in crash rate analysis for intersections and roadway segments, respectively. Chapter 5 documents the results of a synthesis that was conducted to identify and document possible measures to reduce crashes for RITI communities in Idaho and throughout the northwest region. Finally, chapter 6 provides the study conclusions and recommendations.

CHAPTER 2. NEW TOOLS FOR SAFETY ANALYSIS

2.1. Introduction

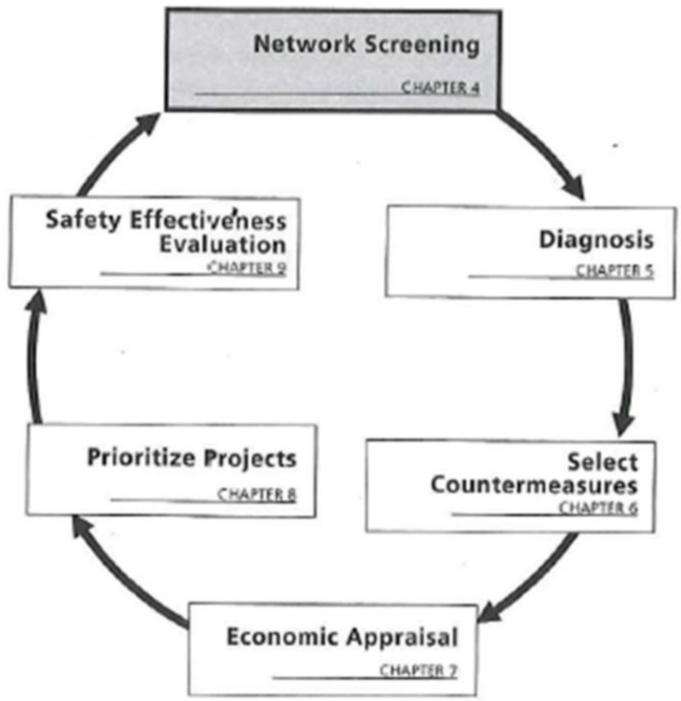
This chapter introduces a new set of Geographic Information System (GIS) tools we created to conduct safety analyses. The tools are based on procedures described in the Highway Safety Manual (HSM), which was published by the American Association of State Highway and Transportation Officials (AASHTO) in 2010. The HSM is a four-volume compendium of calculations and methods that can be used to prioritize roadway segments and intersections for safety improvement (AASHTO, 2010). In 2014, AASHTO released a software package called “Safety Analyst” based on the HSM procedures. State DOTs could license the software for approximately $20,000 per year. This software, however, has not been popular and will be discontinued on June 30, 2022 (AASHTO, 2019). It has been criticized for being overly complicated to use while at the same time lacking in capability. Furthermore, AASHTO’s software has limited integration with GIS.

The tools that we developed for this project are designed to be easy to use and to be highly integrated with GIS. These new tools focus on just one step of the Roadway Safety Management Process (RSMP) which is the fundamental workflow of the HSM. The next section provides background on the RSMP followed by an overview of the new tools which are organized in two toolboxes. Each toolbox is described in a separate section of this chapter. And the chapters that follow each demonstrate the usefulness of the tools by providing results from our two case study examples.

2.2. Roadway Safety Management Process

The central workflow of the HSM is called the Roadway Safety Management Process. The RSMP is a continuous cycle with six ongoing steps shown in Figure 2-1. The first step begins with Network Screening intended to produce a rank-order of roadway segments and intersections based on crash data. Network Screening identifies a small set of locations on the roadway network that are most likely to benefit from safety improvements. The second set, called Diagnosis requires a careful inspection of these locations to determine possible reasons for the high incidence of crashes.

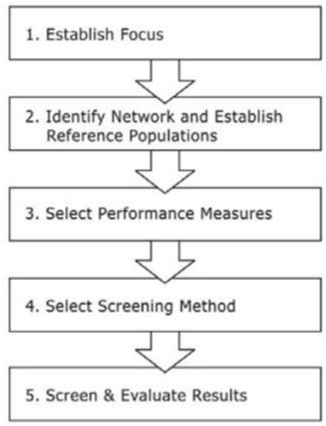
The third step, called Select Countermeasures, is a process of brainstorming and then selecting safety improvement projects for each location. The fourth step, called Economic Appraisal, is a benefit-cost calculation to determine if the cost of a counter measure is economically justified by the anticipated reduction in crashes. The fifth step, called Prioritize Projects, produces a rank-order of the projects that have been identified in the previous steps. After the projects have been planned, programmed, and constructed, the sixth and final step called Safety Effectiveness Evaluation determines if the state DOT’s goals for safety improvement have been achieved and initiates the whole process again.



Source: AASHTO, 2010

Figure 2-1 Roadway Safety Management Process

The tools we developed for this project focus on Network Screening, which, like the other steps in the RSMP, is a complex process with various calculations and procedures. Figure 2-2 Network Screening shows the five sub-steps of Network Screening. The first step, called Establish Focus sets the stage for the rest of the RSMP by answering the question: What is the purpose of this analysis? For example, a state DOT might be doing the analysis to identify projects for a specific funding program or perhaps to mitigate a specific type of crashes such as Vehicle-Animal collisions. The second step, called Identify Network and Establish Reference population identifies the network that matches the goals of the analysis, for example, only rural highways and only Vehicle-Animal collisions. The third step called Select Performance Measures determines what metric will be used to rank-order locations. The HSM identifies 13 possible performance measures, such as “Crash Frequency” and “Crash rate”. The choice of which performance measure(s) to use is dependent on the data that is available. The fourth step called Select Screening Method describes two key methods for segment network screening: Simple Ranking and Sliding Window. For roadways segments the HSM describes three methods: Simple Ranking, Sliding Window, and Peak Searching. The tools created for this project implement the first two screening methods. They are described below. The final step is to screen and evaluate results.



Source: AASHTO, 2010

Figure 2-2 Network Screening

2.3. Overview of New Tools

Our new tools follow procedures and calculations described in the HSM for Network Screening. The example data provided in Chapter 4 of the HSM was replicated and used for tool development and testing to assure the calculations produce similar results. The tools are written in open-source Python code for ArcGIS Pro 2.5. They do not require any installation and can be used directly from any device.

We organized the tools into two toolboxes: the Data Preparation Toolbox and an Analysis Toolbox. The Data Preparation Toolbox consists of five tools for preparing data for GIS analysis, such as creating GIS files and standardizing attribute fields. There is no specific order for using the data preparation tools and some are optional. The optional tools might not be needed depending on the focus of the analysis.

The Analysis Toolbox consists of tools that count the crashes near each feature and ranking locations based on a specified performance measure. The current version of this toolbox includes four performance measures: Crash Frequency, Crash Rate, Equivalent Cost, and Highway Safety Corridor Analysis Score. The HSM describes thirteen possible performance measures), so future work will add more performance measures. The analysis can be performed for roadway segments or intersections, but not at the same time because roadway segments are line GIS features and intersections are point GIS features.

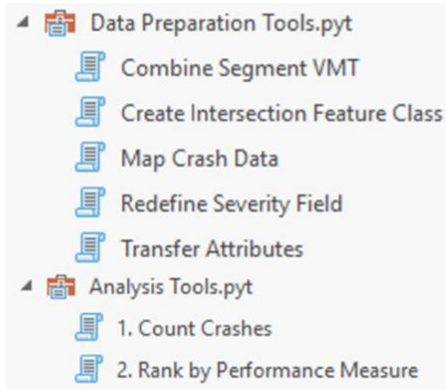


Figure 2-3 Tool Organization

2.4. Data Preparation Toolbox

The five tools in The Data Preparation Toolbox prepare data for a GIS analysis as shown in Figure 2-4. This first step of Network Screening is based on the study Focus. For example, the analysis might only pertain to roadway segments and not intersections. The next step of Network Screening is to identify the relevant network and crashes for the analysis. The HSM explains that analysis should be conducted for a common "reference population." For example, a reference population might be "low volume rural highways" while another reference population might be "High volume urban arterials." Segments can be grouped into their reference population according to common attributes such as Cross-Sectional profile, Annual Average Daily Traffic (AADT), or Dividing/Undivided medians. Intersections can be grouped by attributes such as Traffic Control, Number of Approaches, or Total Entering Vehicles (TEV). The analyst would create a column, perhaps called "Study Group" and identify each feature by a number for the associated group.

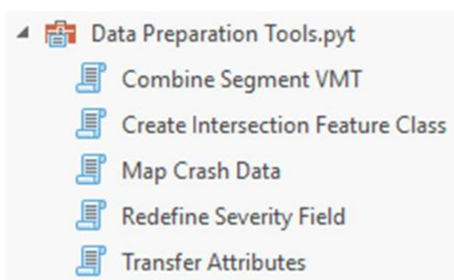


Figure 2-4 Data Preparation Toolbox

2.4.1. Combine Segment VMT

The Combine Segment VMT tool provides a means to aggregate various years of AADT and calculate Vehicle Miles Traveled (VMT). AADT is the vehicle volume along a segment for the whole year divided by

365. It is obtained from permanent vehicle counters that are installed to count vehicles continuously for an entire year. It can also be estimated based on short duration counts. Most state DOTs have AADT estimates for the state highway system as well as for roadways of state significance. VMT is another important traffic monitoring metric and can be calculated by multiplying AADT by 365 days and the length of the road segment.

VMT data provides the exposure element that allows for converting the number of crashes into a crash rate (number of crashes/VMT). Safety analysis uses crash data for multiple years (a 5-year period is typical). Average AADT from multiple year data can be used to calculate Million VMT. The calculations for the tool are:

$$\overline{AADT} = \frac{1}{n}\sum_{years}^{n} AADT_{year} \tag{1}$$

$$Million\ VMT = \overline{AADT} * SegmentLength * 365\ /1{,}000{,}000 \tag{2}$$

This tool is more sophisticated than simply averaging AADT because it can accommodate the fact that road segment delineation sometimes changes from one year to the next. The tool splices all segments to create a common segment length and with a new field for the study period VMT called “SP_VMT”.

2.4.2. Create Intersection Feature Class

The Create Intersection Feature Class tool provides a means to create a new point feature class from a roadway network line feature class. In addition, the tool calculates Total Entering Vehicles (TEV) for each intersection based on the AADT or average AADT of each segment. TEV is a measure of exposure for intersections and allows analyzing the number of crashes in the context of vehicle volume, i.e., as a crash rate (number of crashes/TEV). The TEV calculation is:

$$TEV = \frac{1}{2}\sum_{j} \overline{AADT_j} \tag{3}$$

$$MEV = \frac{TEV}{1{,}000{,}000} * 365 \tag{4}$$

The tool also calculates Million Entering Vehicles (MEV):

2.4.3. Map Crash Data

The Map Crash Data tool provides a means to create a GIS point feature class from a CSV of crash data. The tool was developed for the Idaho Transportation Department (ITD) crash database and platform called WEBCARS, but it can be used for any state database as long as the same data structure is used.

Figure 2-5 is a schematic of the process. WEBCARS does not currently host an application programming interface (API), so records must be downloaded manually. This tool could be improved and streamlined in the future if ITD develops an API. WEBCARS can be queried on one of three levels: Crash, Unit, or Person. The crash-level should be used. Figure 2-6 shows the query interface. There is no limit to what attributes can be included in the crash data. The minimum requirements are the following three fields: latitude, longitude, and severity.

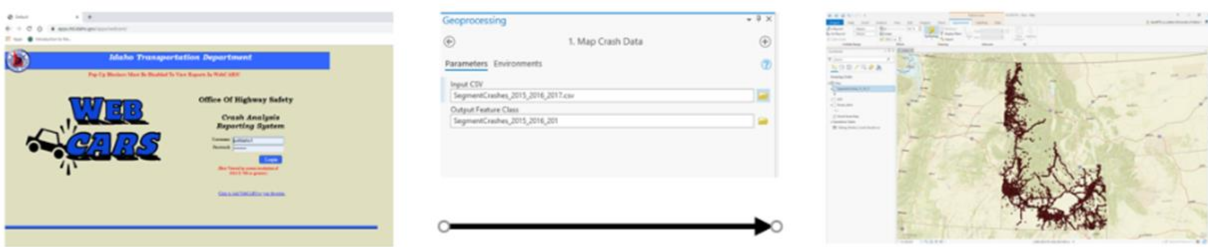


Figure 2-5 Map Crash Data Schematic

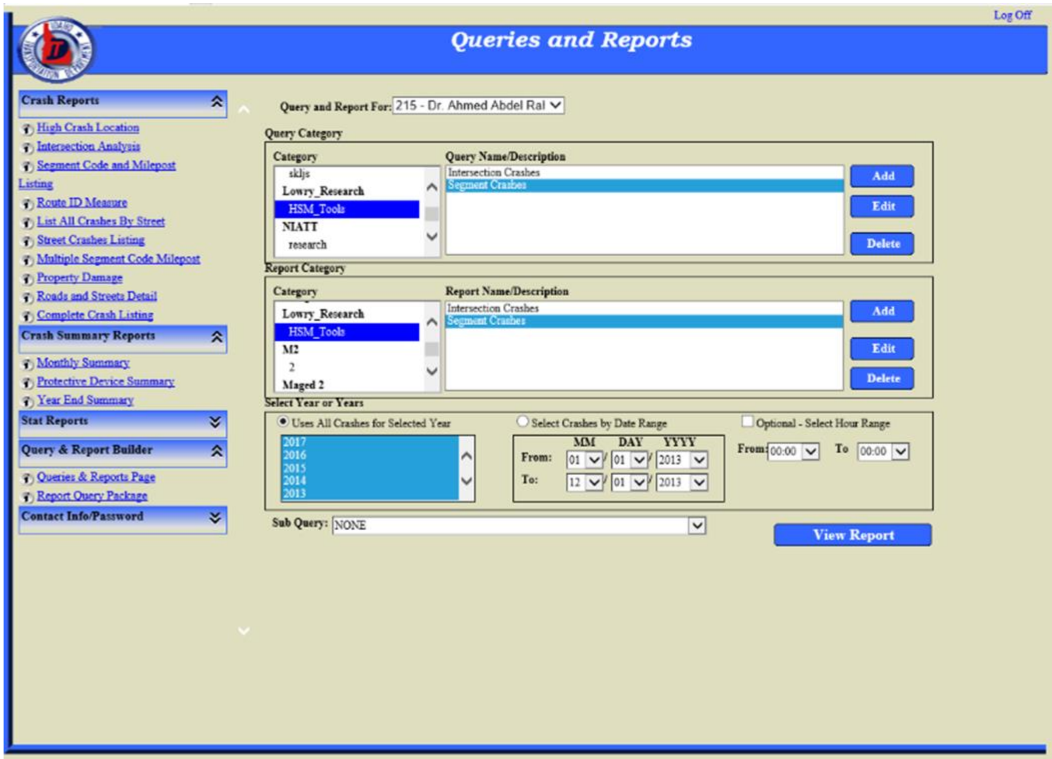


Figure 2-6 WEBCARS Data Query and Report Page

2.4.4. *Redefine Severity Field*

The Redefine Severity Field tool provides a means to interact with any KABCO crash database regardless of the names used for crash severity. The tool redefines the severity field of the input crash feature according to the user provided conversion table. For example, the redefinition for ITD data is as follows: Fatal -> K, A Severity -> A, B Severity -> B, C Severity -> C, and Property Damage Only -> PDO.

2.4.5. *Transfer Attributes*

The Transfer Attributes tool provides a means to reconcile data that is contained across various feature classes. This is useful when the attributes needed to define a segment (e.g., Functional Class, AADT, or Speed) are contained in different geometries. The tool transfers the attributes from the source layer to the target layer using a newly created geometry. If the target layer has features that do not receive the new attribute, these entries are recorded as 'UNKNOWN' to prevent NULL error values when the new feature class is used by other tools. This tool needs to be run multiple times if multiple source layers are required. It creates a copy of the source layer with the updated geometry and appends the attributes to a new column. The new column name must be unique to the feature class otherwise its contents will be overwritten.

2.5. Analysis Tools

The Analysis Toolbox performs the actual analysis. The analysis can be performed for roadway segments or intersections, but not at the same time. Roadway segments are line GIS features and intersections are point GIS features. There are two tools that must be used in consecutive order. The first tool counts crashes at an intersection or along a segment. For segments, this is not a trivial task because, as will be explained in the following section, there are important things to consider to ensure segments of varying length can be compared. The second tool ranks the features according to the chosen performance measure. The current toolbox includes four performance measures: Crash Frequency, Crash Rate, Equivalent Cost, and Highway Safety Corridor Analysis Score.

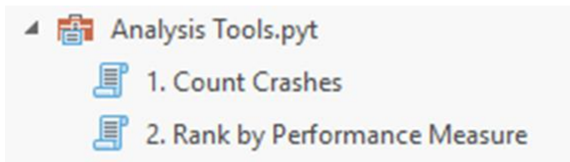


Figure 2-7 Analysis Toolbox

2.5.1. Count Crashes

Crashes along a segment can be calculated in one of two ways: Simple Count or Sliding Window. The choice is made by the tool user as a dropdown box in the tool graphical user interface (GUI). The Simple Count method summarizes the number of crashes along a segment, whereas the Sliding Window method moves an imaginary “window” along the segment to determine the density of crashes for that segment. One benefit of using the Sliding Window is that it can be used to compare segments of different lengths and is generally preferred over the Simple Count for segment analysis. The Simple Count, however, is the only option for counting crashes at intersections. Both methods use a search radius of 300 feet to associate crash latitude/longitude points with the nearest feature.

Simple Count

The Simple Count method requires an input feature class, a set of crash features, and a field defining the severity categories. Our tool assigns each crash to the nearest input feature class within 300 feet. It then summarizes the crashes according to severity and appends a count of each severity to the feature class. An example of the Simple Count method for a segment is presented in Figure 2-8 below (the approach is similar for an intersection).

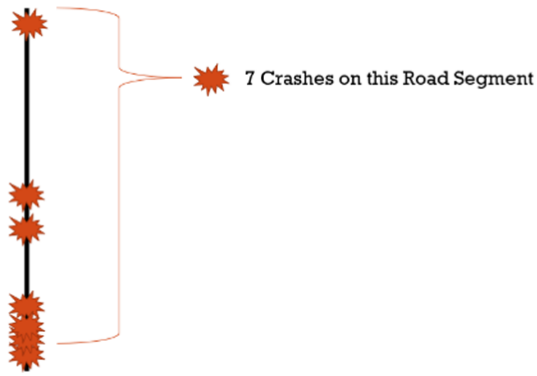
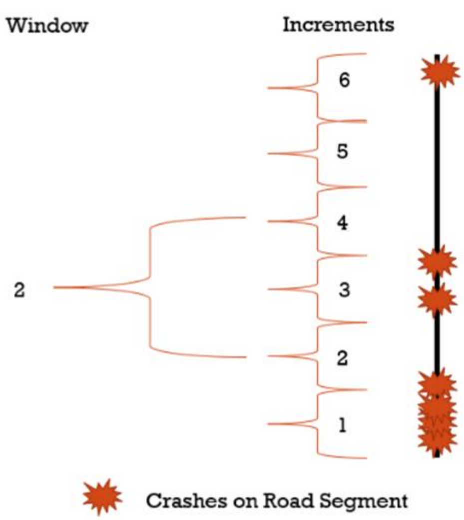


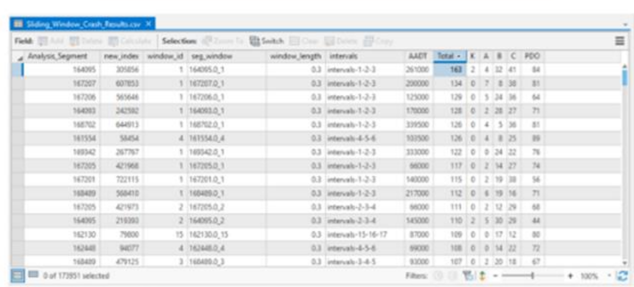
Figure 2-8 Simple Count Method

Sliding Window Count

The Sliding Window method is an extension of the Simple Count method. It pre-processes each segment into a set of intervals (0.1-mile width as the default) and moves a conceptual window with a default width of 0.3 miles across each set of intervals within the road segment. This process is shown in Figure 2-9 using the same example as Figure 2-8. This method counts crashes for each window, and then summarizes the maximum crash count per window for each road segment. It allows for the comparison of crash rates between segments of different lengths because its value represents the worst crash rate within the window and not along the entire segment. The implementation of this method works by dividing the road into segments, associating the crash data to the road segments, completing two spatial joins, and appending the results to the existing feature class. The consolidated results, and unconsolidated output for all windows, can also be exported as optional CSV files.



Window	Increments	Crash Count
1	1, 2, 3	6
2	2, 3, 4	3
3	3, 4, 5	2
4	4, 5, 6	1


Sliding_Window_Crash_Results.csv

Analysis_Segment	new_index	window_id	seg_window	window_length	intervals	AADT	Total	K	A	B	C	PDO
164095	305856	1	164095.0_1	0.3	intervals-1-2-3	261000	163	2	4	32	41	84
167207	607853	1	167207.0_1	0.3	intervals-1-2-3	200000	134	0	7	8	38	81
167206	565646	1	167206.0_1	0.3	intervals-1-2-3	125000	129	0	5	24	36	64
164093	242592	1	164093.0_1	0.3	intervals-1-2-3	170000	128	0	2	28	27	71
168702	644913	1	168702.0_1	0.3	intervals-1-2-3	339500	126	0	4	5	36	81
161554	58454	4	161554.0_4	0.3	intervals-4-5-6	103500	126	0	4	8	25	89
169342	267767	1	169342.0_1	0.3	intervals-1-2-3	333000	122	0	0	24	22	76
167205	421968	1	167205.0_1	0.3	intervals-1-2-3	66000	117	0	2	14	27	74
167201	722115	1	167201.0_1	0.3	intervals-1-2-3	140000	115	0	2	19	38	56
168489	568410	1	168489.0_1	0.3	intervals-1-2-3	217000	112	0	6	19	16	71
167205	421973	2	167205.0_2	0.3	intervals-2-3-4	66000	111	0	2	12	29	68
164095	219393	2	164095.0_2	0.3	intervals-2-3-4	145000	110	2	5	30	29	44
162130	79800	15	162130.0_15	0.3	intervals-15-16-17	87000	109	0	0	17	12	80
162448	94077	4	162448.0_4	0.3	intervals-4-5-6	69000	108	0	0	14	22	72
168489	479125	3	168489.0_3	0.3	intervals-3-4-5	93000	107	0	2	20	18	67

0 of 173951 selected

Figure 2-9 Sliding Window Count Method

2.5.2. *Rank by Performance Measure*

The current version of the Analysis Toolbox includes four performance measures: Crash Frequency, Crash Rate, Equivalent Cost, and Highway Safety Corridor Analysis Score. The HSM describes thirteen possible performance measures, so future work will add more performance measures.

Crash Frequency Ranking

The crash frequency ranking method is the simplest performance measure calculated by dividing the number of crashes for a severity category by the number of years analyzed, as shown in Equation 5. The severity categories used by the Idaho Transportation Department are Fatal (K), A Severity (A), B Severity (B), C Severity (C), and Property Damage Only (PDO). The (Total) category generated by the count tool can also be used to rank features.

$$Crash\ Frequency = \frac{Number\ of\ Crashes}{Period\ in\ Years} \tag{5}$$

Crash frequency is useful in calculating the proportion of crashes along a segment or at an intersection for a severity category. This proportion represents a risk, as it describes the chances that a collision along that feature will result in each severity level (e.g., a fatality given the fatal crash frequency). For example, if two segments both have five fatal crashes, but the total number of crashes is 20 and 80, respectively, they have very different odds that a crash will result in a fatality. The first segment has a 25% chance of experiencing a fatal crash, whereas the second segment has a 6.25% chance of experiencing a fatal crash.

Crash Rate Ranking

The second performance measure incorporated into the ranking analysis tool is the crash rate ranking method calculated by dividing the crash frequency for each feature by a measure of exposure, as shown in Equation 6. This variable is often multiplied by one million to estimate the crash rate per million vehicle miles traveled (VMT) or Million Entering Vehicles (MEV). Segment results produced by the simple ranking method use the length of the segment to calculate its Million VMT value, whereas results produced by the Sliding Window method use the length of the window to calculate its VMT value. This tool requires an additional field defining the Annual Average Daily Traffic (AADT) volume, which can be calculated using the Combine Segment VMT tool in the data preparation toolbox.

$$Crash\ Rate = \frac{Crash\ Frequency}{Exposure\ Measure\ (VMT\ or\ MEV)} \tag{6}$$

Equivalent Cost Ranking

The third performance measure is the equivalent cost ranking method. This method summarizes the product of the cost of each severity category, i, by the number of crashes, N, to represent a total monetary cost, as shown in Equation 7. Table 2.1 shows the estimated economic costs for each severity type summarized from the 2014 Crash Report published by ITD. Cost tables can be modified depending on the average cost of a severity category in a year or range of years.

$$Equivalent\ Cost\ Score = \sum CrashCost_i * N_{observed,i} \quad (7)$$

Table 2.1 ITD's Cost Table for Cost Equivalence

Economic Cost of Idaho Crashes: 2014 Estimates			
Incident Description	**Total Occurrences**	**Cost Per Occurrence**	**Cost Per Category**
Fatalities	186	$6,493,502	$1,207,791,342
Serious Injuries	1,273	$323,382	$411,665,088
Visible Injuries	3,689	$90,577	$334,140,238
Possible Injuries	6,806	$60,040	$408,633,680
Property Damage Only	13,742	$6,951	$95,520,433
Total Estimate of Economic Cost			**$2,457,750,780**

(Source: ITD, 2014)

Highway Safety Corridor Analysis Ranking

The fourth performance measure is not found in the HSM but instead was developed for the Idaho Transportation Department (ITD). The performance measure groups segments by functional class and ranks each segment relative to the other segments within its functional class by calculating the mean crash rate for the group. The calculation does this for injury crashes and total crashes. These are then combined for a composite HSCA Score with 70% of the score for injury crashes and 30% for the total crash rate as shown in Equation 8.

$$HSCA\ Score_{Group} = \frac{7}{10} * \frac{Injury\ Crash\ Rate}{Mean\ Injury\ Crash\ Rate} + \frac{3}{10} * \frac{Total\ Crash\ Rate}{Mean\ Total\ Crash\ Rate} \quad (8)$$

Symbolizing and Presenting Results

When the tool completes, it symbolizes and maps the results so they can be visually interpreted and presented. First the tool rescales and ranks by study group. This is done to standardize the performance measure between two values to make results comparable between performance measures. The default setting is to values between 0 and 1, but the same tool can be used to perform other rescaling's. It also takes the rescaled values of the previous output and ranks it within categories, with eight as the default value. This ranking can be performed using the Equal Interval Method, which divides the data into equal portions according to their Rank, or the Quantile Method, which divides the data into unequal records into each category if the data is not evenly distributed. Finally, this tool has an additional parameter for defining Study Groups for the Rankings. This means that given a Study Group Field, it rescales and ranks the values of each performance measure within that group. If a Study Group is not provided, the rescaling and ranking are performed on all the values.

Next the tool symbolizes and maps the Performance Measure. This is used to symbolize the results of Intersections and Segments according to the ranked field. These layers require a consistent geometry type (point or line) as well as a consistent symbology field, such as the ranked field. Therefore, these fields are consistently named to ensure that the results are appropriately symbolized according to their geometry type. The results of the ranking method are appended to the feature layer as a new attribute named according to the performance measure that produced it.

CHAPTER 3. CASE STUDY 1: INTERSECTION SCREENING

3.1. Introduction

This chapter presents a case study to demonstrate how the new tools can be used for intersection screening, the first step of the Roadway Safety Management Process described in the HSM. The goal of intersection screening is to rank-order intersections based on crash data and identify locations that would most likely benefit from safety improvement. The analysis was conducted for all intersections on the Idaho State Highway System. In practice, the analysis would likely be done only for a subset of intersections, such as only for signalized intersections on urban arterials. Our case study included all intersections for illustration purposes. Four years of crash data (2013 to 2017) were used in the analysis. This chapter presents the case study as a series of steps to illustrate an example workflow that an analyst could follow.

3.2. Step 1: Map Crash Data

The first step was to obtain and map a dataset of crashes. The WEBCARS query used for this case study included all intersection crashes. Note that the file downloaded from WEBCARS includes a text description at the top that must be removed so that the file can be saved as a CSV file. There is no limit to what attributes can be included in the crash data. The minimum requirements are the following three fields: latitude, longitude, and severity. The Map Crash Data tool uses the latitude and longitude to map the data as shown in Figure 3-1.

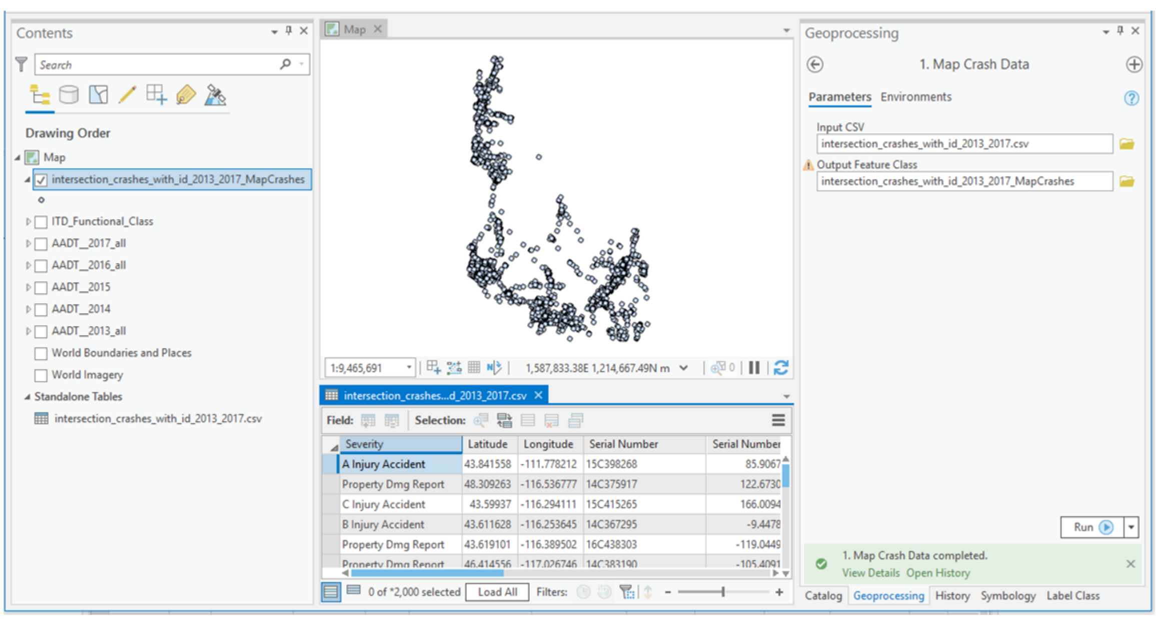


Figure 3-1 Map Crash Tool Interface and Results

3.3. Step 2: Create Intersection Feature Class

Step 2 creates a GIS feature class for intersection points. The input for this tool is a roadway network with AADT values for each roadway segment, as shown in Figure 3-2. In addition to creating the intersection points, the tool uses the AADT values of all legs of the intersection to calculate TEV and MEV, regardless of whether they are 3 or 4 legged intersections (only one AADT value will be used, so if multiple years of AADT are needed for the analysis, then the tool called Combine Segment VMT should be used first). The Create Intersection Feature Class tool does not need to be used again for subsequent analysis unless the AADT values have changed.

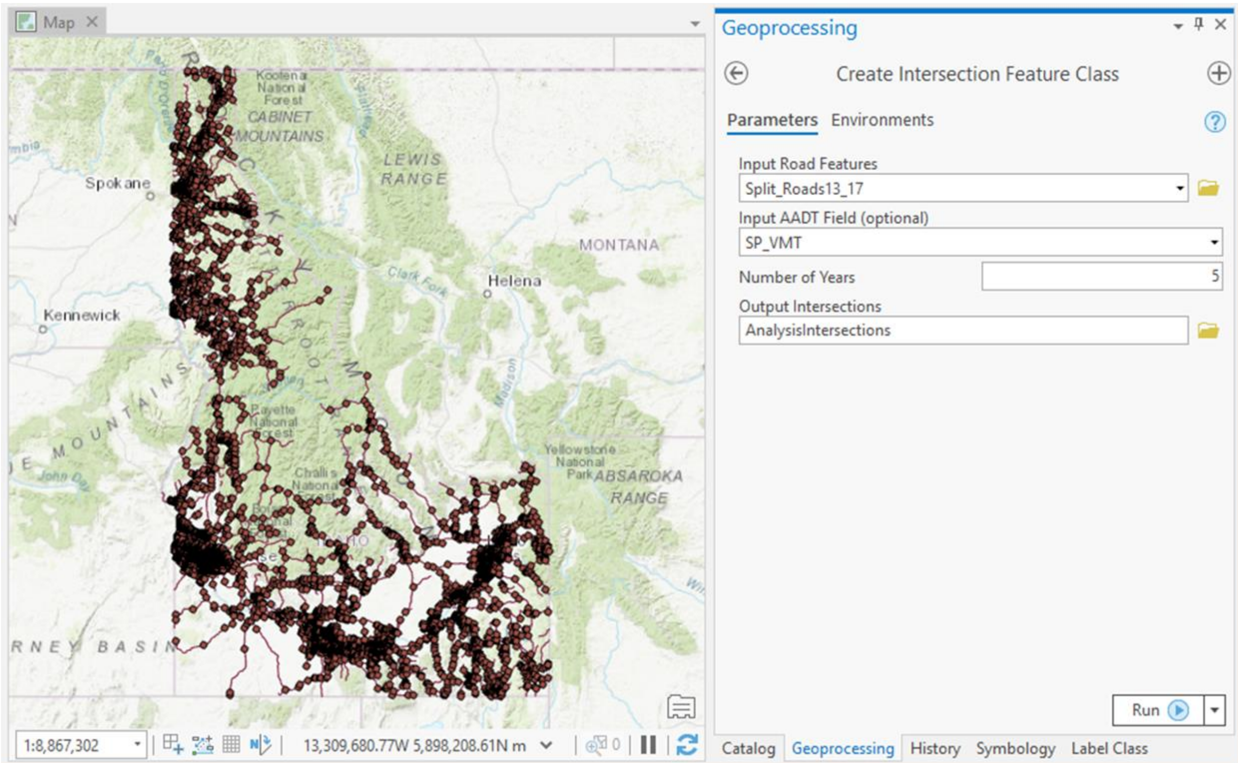


Figure 3-2 Creating Intersections from a Road Network

3.4. Step 3: Count Crashes

Step 3 associates the crash data with the intersection feature points. This is done by running the tool Count Crashes, shown in Figure 3-2. There are two methods to do this. The first method, called Simple Count, associates all crashes to the adjacent segment. The second method, called Sliding Window, divides the segments into increments and provides a count for each increment for a “window” that is sliding along the segment. For intersection data the only viable method is the Simple Count. The other method is only possible for segment screening.

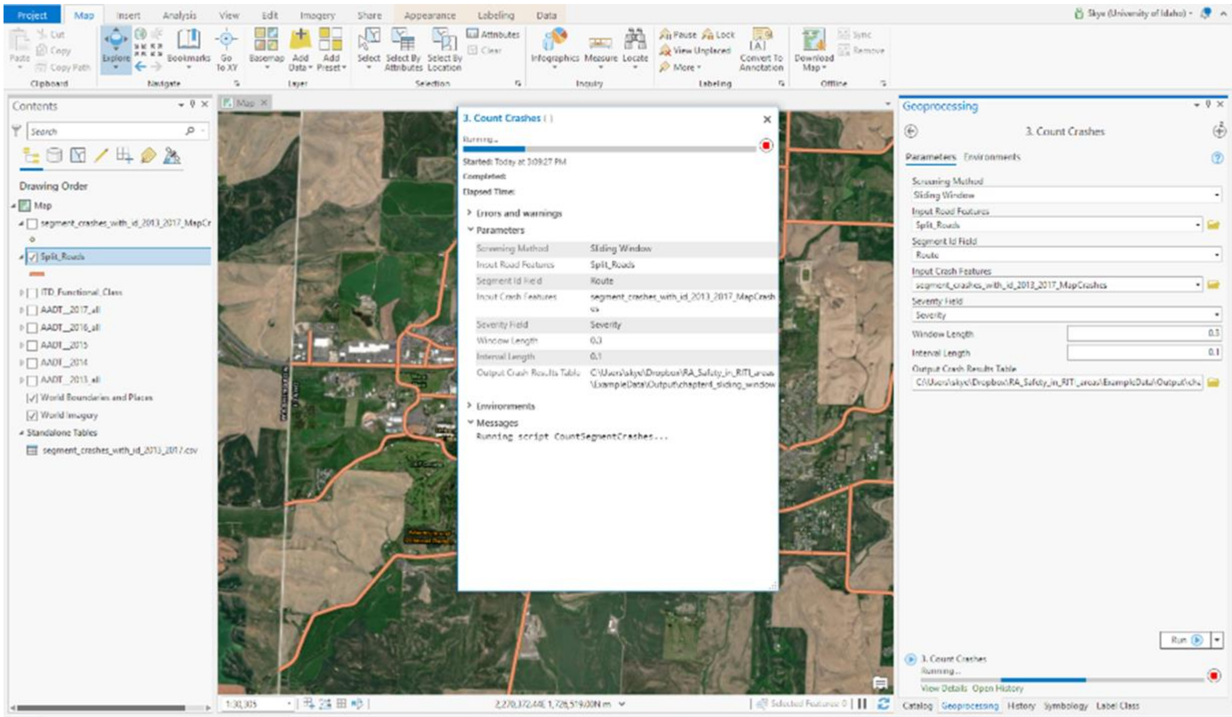


Figure 3-3 Total Crash Count Output

3.5. Step 4: Rank Crashes

The final step is to use the Rank Crashes command to create a rank order of the intersections based on a specified performance measure. Three methods were used in the case study for illustration: Crash Frequency, Crash Rate, and Equivalent Cost. The results of these methods will be compared to give an overall indication of which intersections could benefit from improvements and would be possible candidates for a Highway Safety Management review.

3.5.1. Crash Frequency Intersection Ranking

Intersections were ranked based on Crash Frequency. For illustration purposes this performance measure was used twice: once for total crashes and then again for fatal crashes. The tool displays the results with symbolized maps and creates a table output that can be opened in Excel. Nine out of the top ten highest crash frequencies occurred in the greater Boise area, as shown below in Figure 3-4. These values ranged between 85 and 140. Since crash frequency does not take AADT into account, these locations reflect intersections with a high traffic volume with the top 10 intersections having TEV value between 58,100 and 388,250. These indicate that the selected intersections have a between 106 million and 709 million vehicles entering within the five-year study period. The intersection ranked in the 4th position with 115 crashes 250 MEV is in Pocatello, ID.

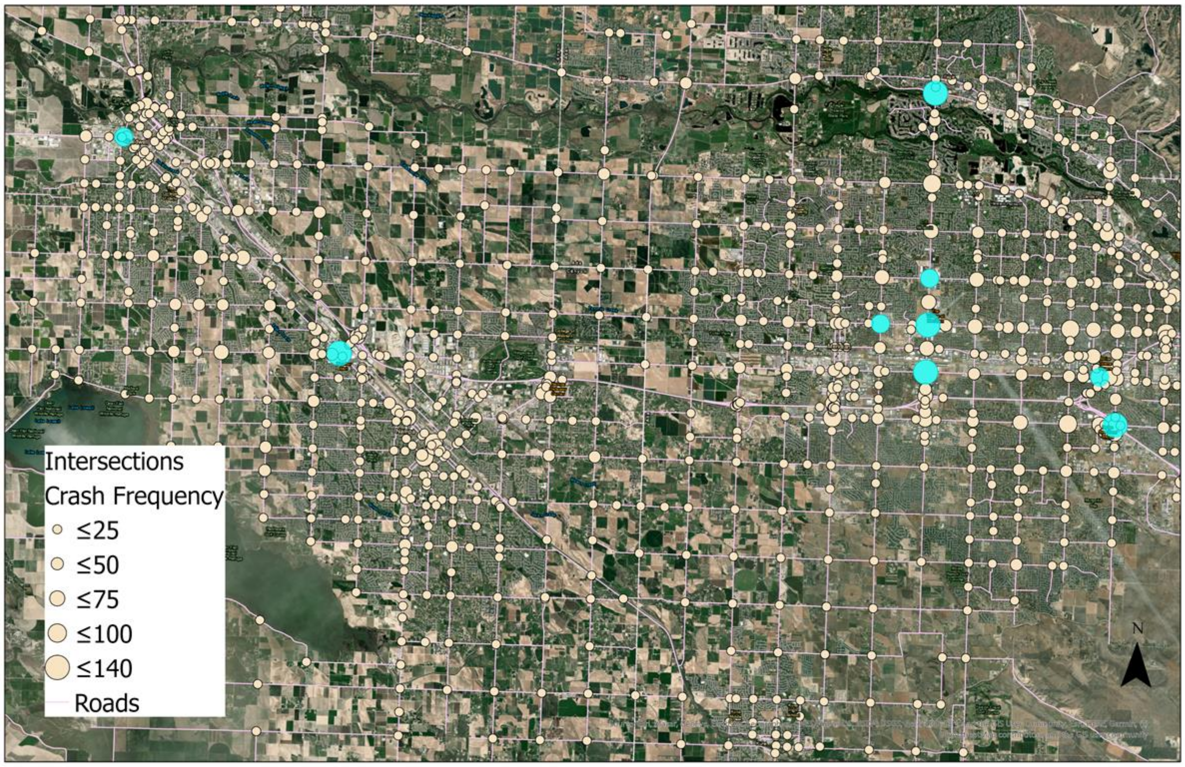


Figure 3-4 Nine out of Top 10 Intersections ranked by Total Crash Frequency

In addition to the total number of crashes, we also identified which intersections had the highest frequency of fatal crashes. A summary of the Top 5 Fatal Crash Intersections Ranked by Frequency is shown in Table 3.1. The highest-ranked intersection with a total of 3 crashes was in Post Falls, as shown in Figure 3-5. Approximately 8% of the 36 crashes that occurred at that location during the study period resulted in a fatality. Four other intersections had a total of 2 fatal crashes. Three were in Nampa, ID, and one was along US 95 adjacent to the Clearwater River Casino and Lodge.

Table 3.1 Top 5 Intersections Ranked by Fatal Crash Frequency

Site	Intersection	Jurisdiction	Rank	Fatal	Total	Fatal/Total
121	W Prairie Ave and N Pleasant View Rd.	Post Falls, ID	1	3	36	8.3%
476	US 95 & Nez Perce Rd.	Nez Perce Reservation	2	2	10	40%
891	Farmway & Homedale Rd.	Caldwell, ID	2	2	13	15.4%
1034	Lake Ave & Orchard Ave	Nampa, ID	2	2	7	28.6%
1485	Robinson Rd. & E. Locust Ln.	Canyon County, ID	2	2	18	11.1%

Figure 3-5 Highest Ranked Intersection ranked by Fatal Crash Frequency in Post Falls, ID

3.5.2. Crash Rate Intersection Ranking

Intersections were ranked based on Crash Rate. This performance measure is the total number of crashes divided by total number of entering vehicles (TEV). The Top 10 intersections are shown in Figure 3-6. This performance measure often ranks intersections with low traffic volumes (less than 6900), where the total number of crashes was also small (less than 5). In most cases, the TEV was less than a thousand. Therefore, it is difficult to interpret these results without first sorting the intersections into groups with similar traffic volumes.

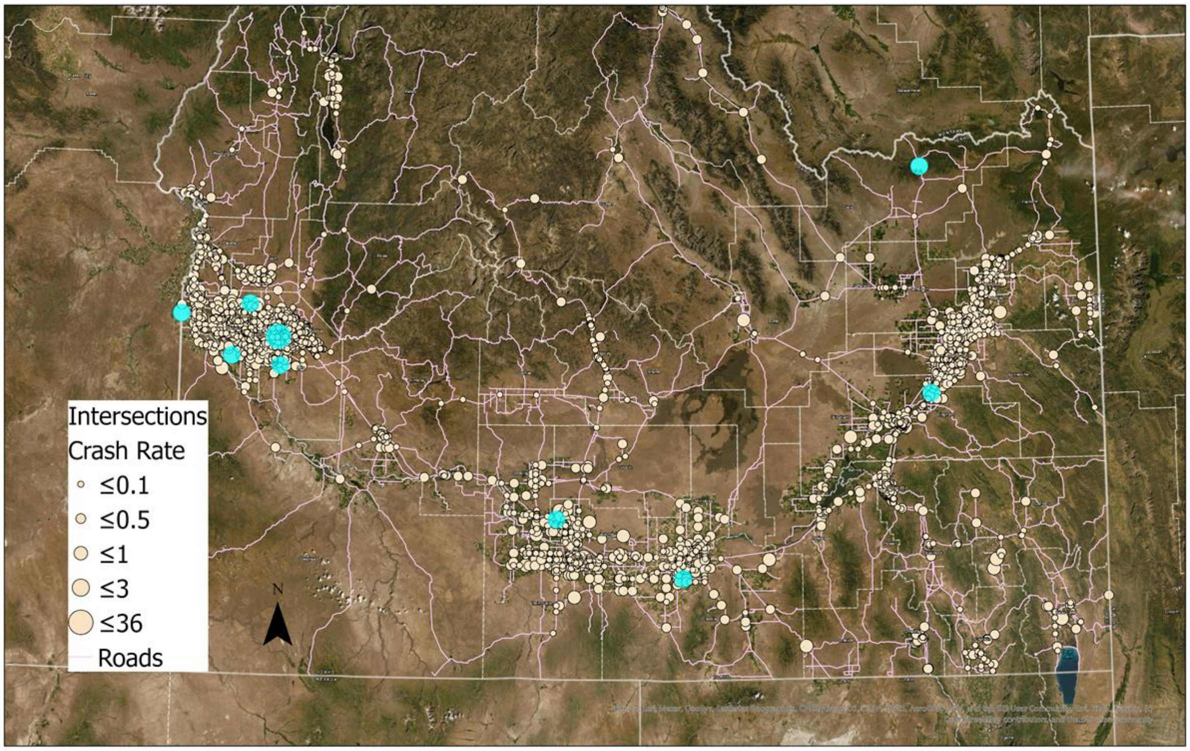


Figure 3-6 Top 10 Intersections ranked by Crash Rate

3.5.3. Equivalent Cost Intersection Ranking

Intersections were ranked using the performance measure Equivalent Cost tool. The values ranged between $4,707, which was the sample cost for a single property-damage-only crash and 28.05 million dollars. The rankings are similar to what was produced by using Crash Frequency. The highest-ranked intersection with a total of 3 fatal crashes was in Post Falls. The intersection ranked in the 3rd position is intersection 476 with a total equivalent cost value of 17.93 million dollars, was also highly ranked by the crash frequency performance measure. It is located along US 95 adjacent to the Clearwater River Casino and Lodge, as shown in Figure 3-7.

Figure 3-7 Highly Ranked Intersection near Clearwater River Casino

3.6. Results and Conclusions

This case study demonstrates how our new system of tools can be used for Network Screening. The tools create useful maps to show spatial patterns. The new tools we developed assist transportation agencies to effectively implement the Roadway Safety Management Process to reduce the number of crashes as well as their severity. While ranking results can vary between performance measures, they often identify similar intersections that could benefit from improvements.

Three ranking methods were evaluated for this case study: Crash Frequency, Crash Rate, and Equivalent Cost. The results of Crash Frequency and Equivalent Cost were often in agreement, with the Equivalent Cost method being able to more precisely differentiate between locations with a similar number of fatal crashes but differing numbers of less severe crashes. Results from the Crash Rate method were sensitive to the range of values for the exposure measure. Intersections with low MEV values produced higher rankings compared to intersections with a similar frequency of crashes but a lower traffic volume. Therefore, it is important to only compare intersections with similar traffic volumes.

CHAPTER 4. CASE STUDY 2: ROADWAY SEGMENT SCREENING

4.1. Introduction

This chapter presents a second case study to demonstrate how our new tools can be used for roadway segment screening. Screening is the first step of the Roadway Safety Management Process which is described in the HSM. The goal of segment screening is to rank-order roadway segments based on crash data and identify locations that would most likely benefit from safety improvement. The analysis was conducted for all segments on the Idaho State Highway System. In practice, the analysis would likely be done only for a subset of segments, such as for rural two-lane highways. This case study included all segments for illustration purposes. Four years of crash data (2013 to 2017) were used in the analysis. This chapter presents the case study as a series of steps, to illustrate an example workflow that an analyst could follow.

4.2. Step 1: Map Crashes

The first step was to obtain and map a dataset of crashes. The WEBCARS query used for this case study included all crashes that occurred along roadway segments. Note the file that is downloaded from WEBCARS includes a text description at the top that must be removed so that the file can be saved as a CSV file. There is no limit to what attributes can be included in the crash data. The minimum requirements are the following three fields: latitude, longitude, and severity. The Map Crash Data tool uses the latitude and longitude to map the data.

4.3. Step 2: Combine Study Period VMT for Segments

The second step was to determine the appropriate AADT to use for analysis. The Combine Segment VMT tool was used to combine multiple years of AADT. Five years of AADT (2013 to 2017) were combined to correspond with the five years of crash data. Figure 4-1 shows the tool interface.

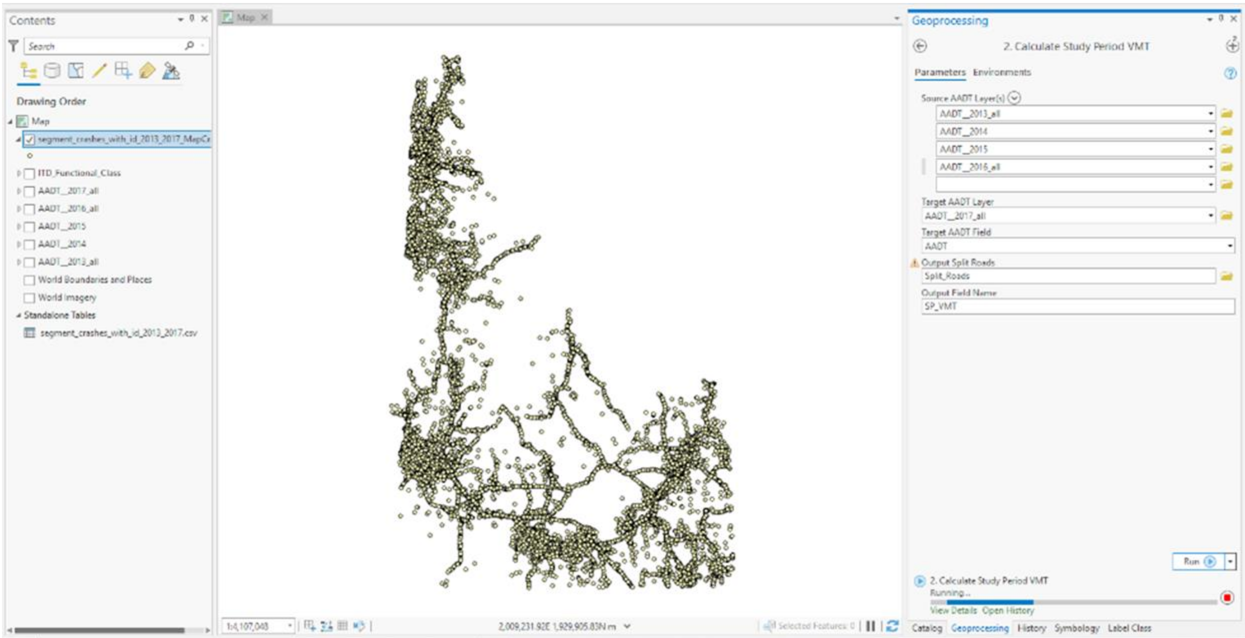


Figure 4-1 Calculating Study Period VMT from Multiple AADT Feature Classes

4.4. Step 3: Count Crashes

The third step associates the crash data with the segments. There are two methods to do this. The first method, called Simple Count, associates all crashes to the adjacent segment. The second method, called Sliding Window, divides the segments into increments and provides a count for each increment for a "window" that is sliding along the segment. Table 4.1 shows the difference in results for the Simple Count method and for Sliding Window method for a segment with the largest crash count. One benefit of using the Sliding Window method is that it can be used to compare segments of different lengths. For example, the Sliding Window counts reflect the largest crash count for a window along a segment and not the entire segment as with the Simple Count method.

Table 4.1 Comparison of Simple Count and Sliding Window Count

Method	Segment length	Total Crashes	PDO Crashes	C Severity Crashes	B Severity Crashes	A Severity Crashes	Fatal Crashes
Simple Count	< 1 to 91 miles	256	140	111	53	26	6
Sliding Window	Window length (0.3 miles)	72	50	25	16	5	3

4.5. Step 4: Rank Crashes

The final step is to use the Rank Crashes command to create a rank order of the roadway segments based on a specified performance measure. Crashes were ranked using four performance measures: Crash Frequency, Crash Rate, Equivalent Cost, and Highway Safety Corridor Analysis. The results of these methods will be compared to give an overall indication of what intersections could benefit from improvements and would be possible candidates for an HSM review.

4.5.1. Crash Frequency Segment Ranking

For illustration purposes, the Crash Frequency was determined with the Simple Count and Sliding Window Count methods.

Simple Count

Crash Frequency was used as the performance measure in this step. Seven out of the top ten highest crash frequencies occurred on I-84 and I-15 in the counties of Bannock, Bingham, Canyon, Elmore, and Twin Falls, as shown in Figure 4-2 (top) and summarized in Table 4.2. Crash frequencies ranged between 5 and 6 fatal crashes making up approximately 3% of the total number of crashes for the segment, with one outlier having a proportion of fatal crashes equal to 6.6%. One segment along US-12 was ranked in 10^{th} place and had a relatively low percentage of fatal crashes with 4.2%. The ratio of crashes that resulted in a fatality or 'A' Severity injury was between 8.5% and 18.3%. These values are much higher than the 0.3% of crashes predicted by the Henrich triangle (HSM 2010). Two additional segments had a fatal crash proportion of approximately 11% and an FA proportion between 16% and 21%. US-95 in Idaho county between mile markers 197 and 214 shown in Figure 4-2 (middle), and US-12 in Idaho county between 99 and 162 shown in Figure 4-2 (bottom). Both segments are in remote areas where there could be underreporting of less severe injuries.

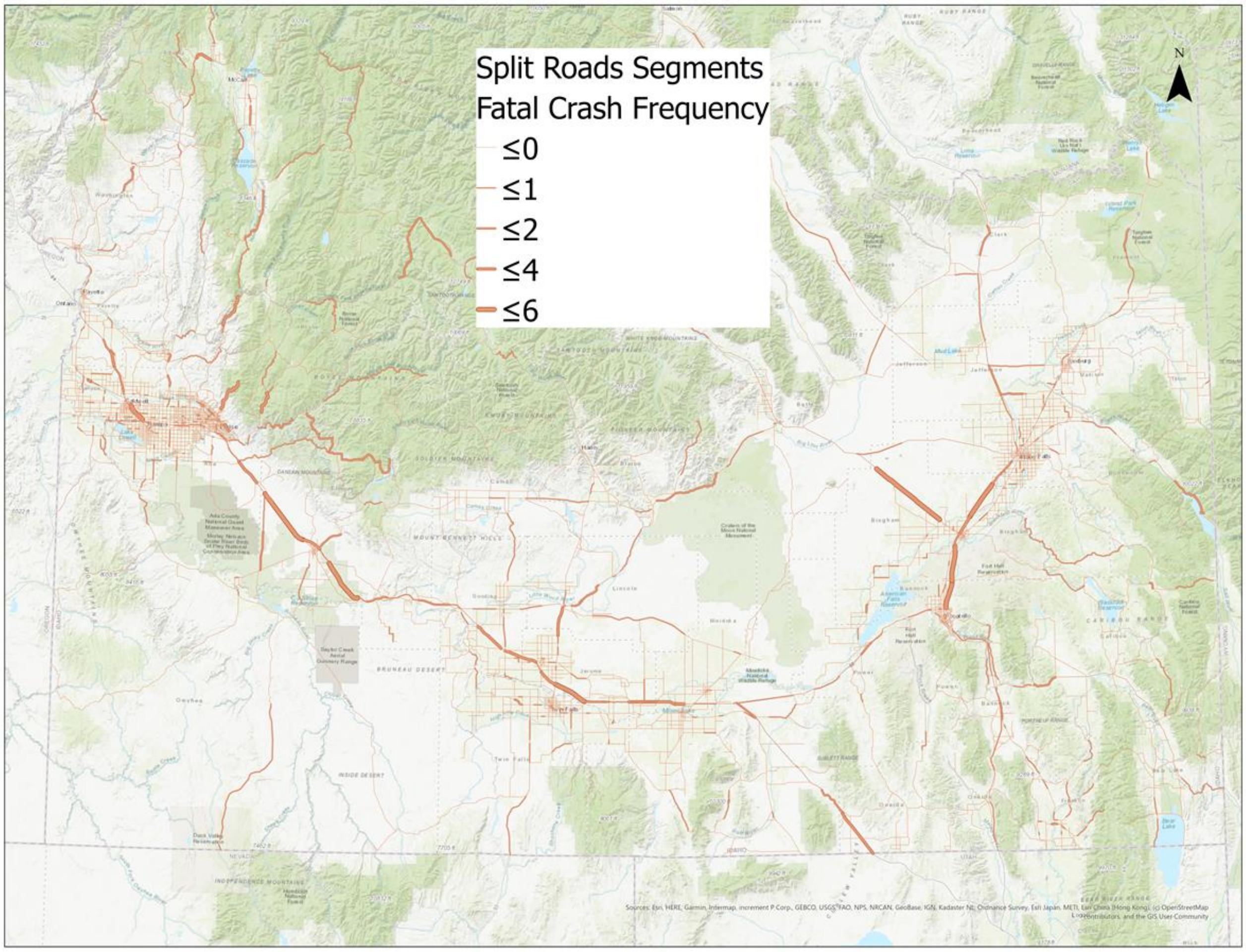


Figure 4-2 Segments ranked by Fatal Crash Frequency with Simple Count.

Table 4.2 Top 10 Segments Ranked by Crash Frequency Using Simple Count

ID	Name	County	BMP	EMP	Length (miles)	Rank	Fatal	A	Total	Fatal/Total (%)	FA/Total (%)
001010	I-84	Twin Falls	173	182	9	1	6	8	91	6.6	15.4
001010	I-84	Canyon	29	34	5	2	6	26	200	3.0	16.0
001010	I-84	Elmore	74	90	24	3	6	20	238	2.5	10.9
001540	US-95	Idaho	197	214	17	4	6	3	57	10.5	15.8
001330	I-15	Bannock	73	80	7	5	5	12	146	3.4	11.6
001330	I-15	Bingham	80	89	9	6	5	13	196	2.6	9.2
001330	I-15	Bingham	98	108	10	7	5	10	177	2.8	8.5
001010	I-84	Elmore	100	112	12	8	5	17	156	3.2	14.1
002240	US-26	Bingham	278	300	22	9	5	4	43	11.6	20.9

001910	US-12	Idaho	99	162	63	10	5	17	120	4.2	18.3

Sliding Window

Crash Frequency was also used with the Sliding Window method. The results are different when compared to the Simple Count. Five out of the top ten highest crash frequencies occurred on I-84 and I-15 in the counties of Bingham, Canyon, Kootenai, and Oneida. It is important to note that the rankings of the Sliding Window output represent the highest crash count for a window within the analysis segment and do not represent the total count for the segment. Therefore, the window with the highest number of total crashes is not necessarily the same window with the highest number of fatal or severe crashes. Thus, fatal crashes are not presented as a proportion of the total, as shown in Table 4.3. Figure 4-3 shows a selection of four segments that indicate many fatal crashes within a concentrated area.

Table 4.3 Top 10 Segments Ranked by Crash Frequency Using Sliding Window Count

ID	Name	County	BMP	EMP	Length (miles)	Rank	Fatal	A Severity	Total
002140	ID-21	Boise	21.99	28.89	7	1	3	3	6
002700	Warm Springs Ave	Ada	2.11	4.10	2	1	3	1	7
001330	I-15	Bingham	107.99	113.21	5	2	2	1	11
001010	I-84	Oneida	262.51	275.65	13	2	2	1	5
001010	I-84	Canyon	28.68	33.60	5	2	2	5	26
001330	I-15	Bingham	79.90	89.01	9	2	2	2	10
001540	US 95	Idaho	196.75	213.69	17	2	2	1	4
001682	I-90	Kootenai	0	0.22	0.25	2	2	1	6
002070	US-20	Canyon	11.31	12.23	1	2	2	1	4
002360	ID-34	Caribou	91.93	93.95	2	2	2	0	9

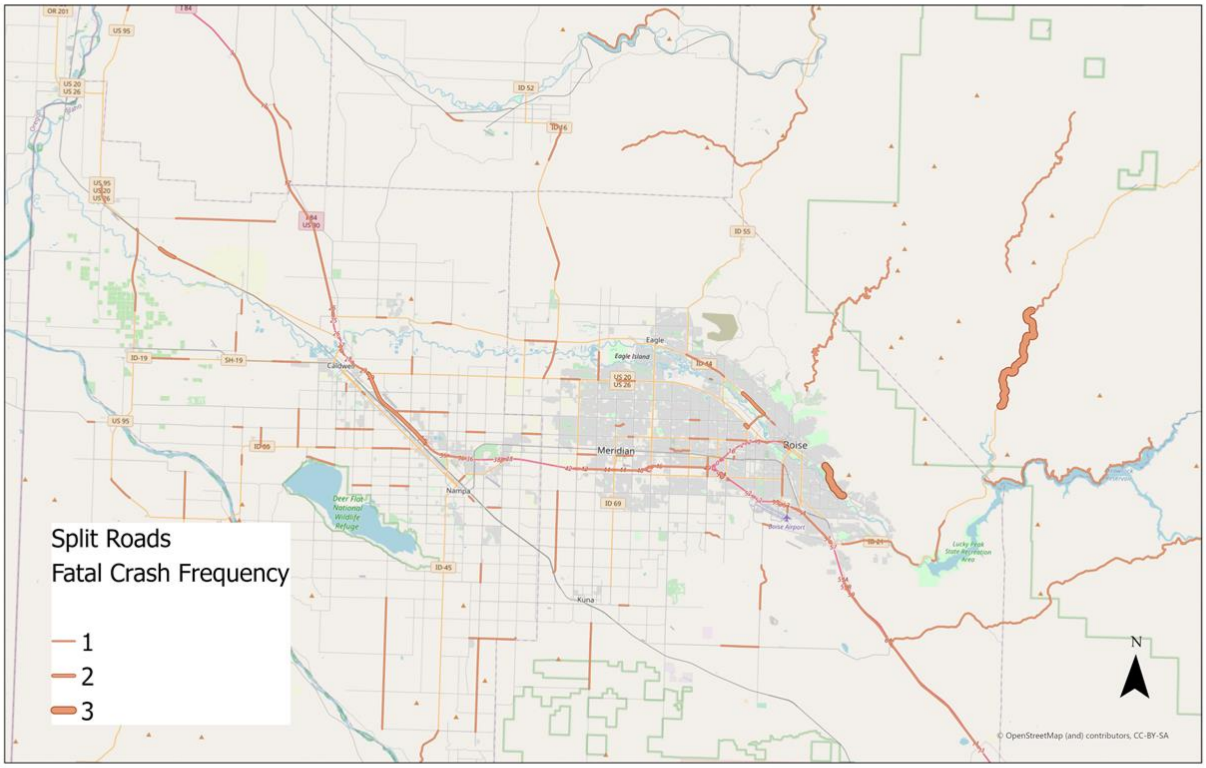


Figure 4-3 Segments ranked by Fatal Crash Frequency with Sliding Window.

4.5.2. Crash Rate Segment Ranking

The segments were ranked by Crash Rate, which is the total number of crashes divided by VMT. The analysis was done with the Sliding Window count. Crash Rate uses VMT to normalize crash frequency based on exposure. Table 4.4 shows that this performance measure tends to rank segments with the smallest traffic volume the highest, even when thresholds limit the segments with minimal traffic volumes. Table 4.5 shows the top ten fatal crash segments ranked by the crash rate produced by the sliding window method. To address this issue, we encourage the user to group road segments into similar categories according to ranges of VMT values before they are ranked.

Table 4.4 Top 10 Critical Segments for Different Study Groups

	Range of Values for Top 10 Critical Segments		
Study Group	**Segment VMT**	**Number of Crashes**	**Crash Rate**
All Segments	50 – 250	1 – 6	0.0200 – 0.0400
≥ 1,000 VMT	1,000 – 2,700	4 – 3	0.0032 – 0.0064
≥ 10,000 VMT	10,000 – 16,500	1 – 7	0.0001 – 0.0003
≥ 100,000 VMT	107,000 – 163,500	41 – 72	0.0004 – 0.0006

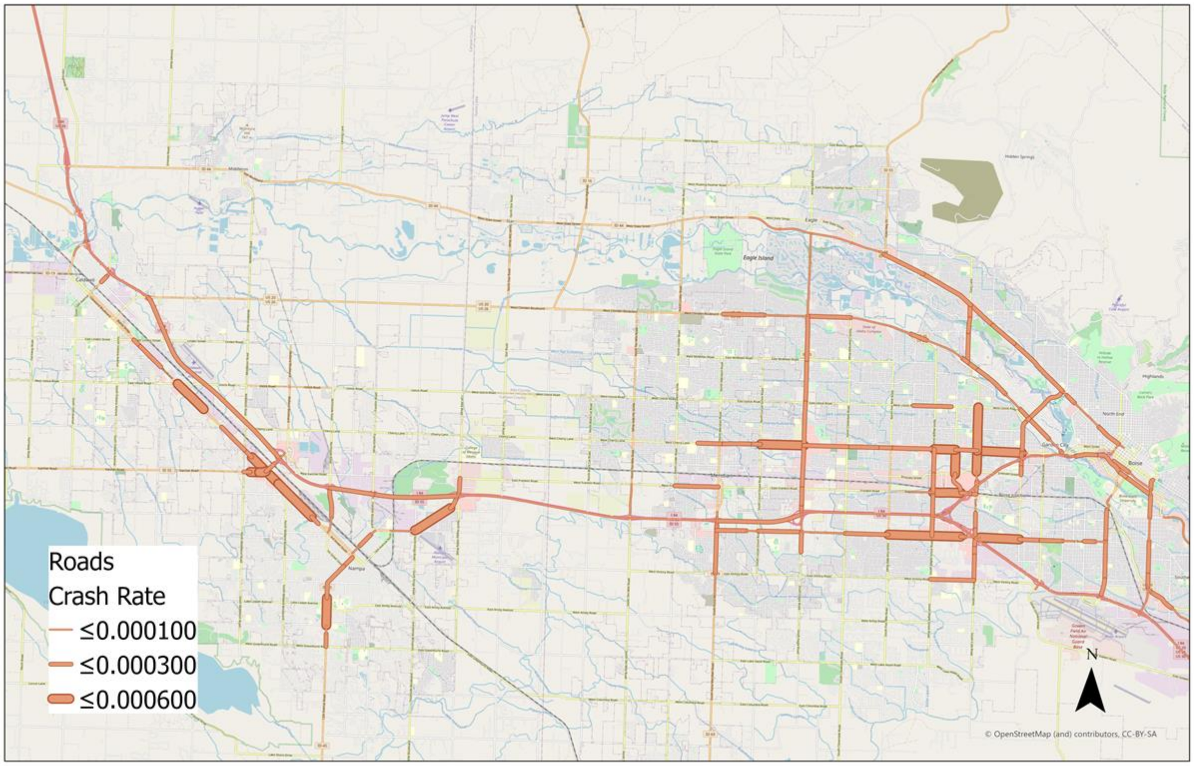


Figure 4-4 Crash Rate rankings for Segments with VMT ≥ 100,000 in the Boise area

4.5.3. *Equivalent Cost Segment Ranking*

Segments were ranked using the performance measure Equivalent Cost tool and the Sliding Window method. The results are very similar to those produced using the Crash Frequency performance measure. One benefit of the Equivalent Cost performance measure is that it emphasizes fatal crashes, while also differentiating between segments with the same number of Fatal crashes. The top ten crash frequency results only produced two rankings because each segment window only experienced two or three fatal crashes. The equivalent cost method, however, can distinguish between segment windows according to less severe crash counts, such as A Severity crashes.

Table 4.5 Top 10 Segments Ranked by Equivalent Cost

ID	Name	County	Length (miles)	Rank	Fatal	A Severity	Total	Equivalent Cost (Millions of Dollars)
002140	ID-21	Boise	6.9	1	3	3	6	26.55
002700	Warm Springs Ave	Ada	1.99	2	3	1	7	25.67
001010	I-84	Canyon	4.92	3	2	5	26	20.10
025270	W. Ustick Rd.	Ada	0.19	4	2	4	12	18.43
002130	W. State St.	Ada	1.58	5	2	1	26	18.21
001330	I-15	Bingham	9.11	6	2	2	10	18.16
001330	I-15	Bingham	5.22	7	2	1	11	17.57
001010	I-84	Oneida	13.14	8	2	1	5	17.49
005510	ID-36	Franklin	1.62	9	2	1	6	17.39
002240	US-26	Bingham	21.11	10	2	1	5	17.38

4.5.4. *HSCA Segment Ranking*

The final performance measure used was the Highway Safety Corridor Analysis (HSCA). This method was developed for ITD and is not found in the HSM. The results of the HSCA method differ from the previous methods because the ranking is developed for each subcategory of road features analyzed. Since this performance measure incorporated VMT to normalize the crash rate, it is also sensitive to traffic volumes. Therefore, it ranked roads with low traffic volumes in a similar way to the crash rate performance measure. The benefit of this measure is that it can be applied to multiple study groups or VMT classifications. The results of this classification are shown in Figure 4-5.

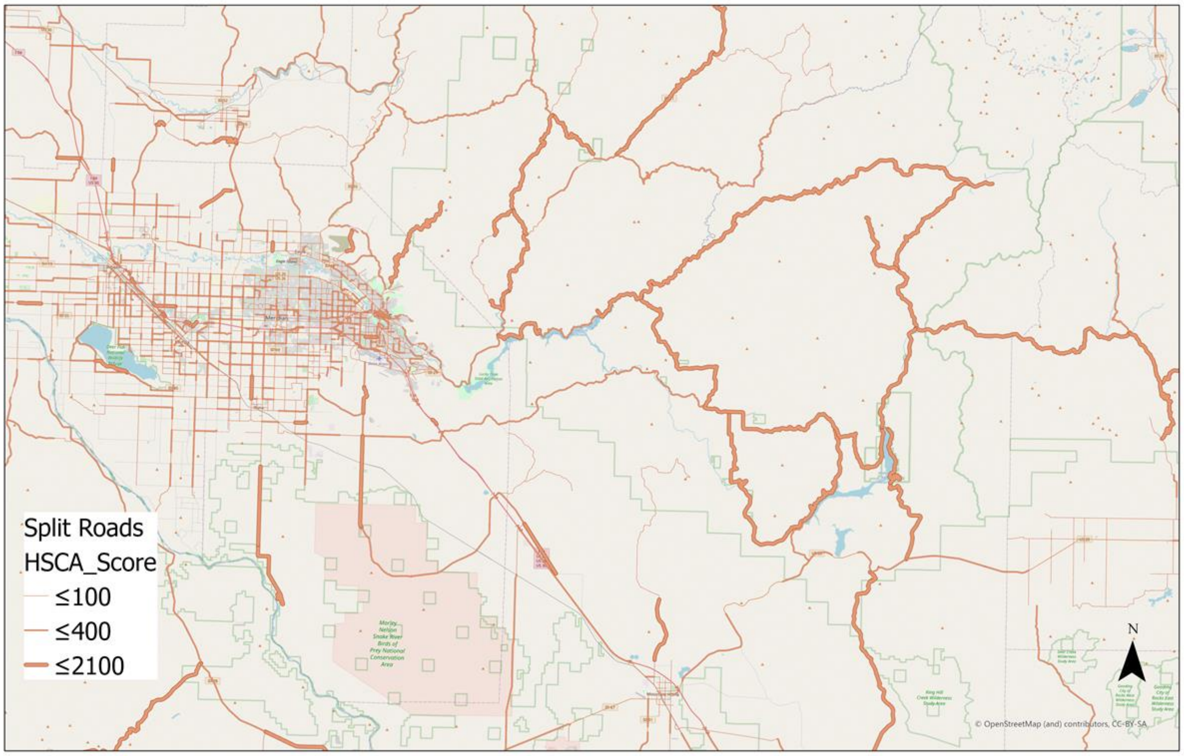


Figure 4-5 HSCA Results: Northeast of Coeur d'Alene, East of Boise Area, and Southeast Idaho

4.6. Results and Conclusions

This case study demonstrates how our new system of tools can be used to screen segments and identify segments that would most benefit from safety improvement. These segments were mapped and symbolized to show spatial patterns within Idaho. The new tools we developed assist transportation agencies to effectively implement the Roadway Safety Management Process to reduce the number of crashes as well as their severity. While ranking results can vary between performance measures, they often identify similar intersections that could benefit from improvements.

Four ranking methods and two count methods were evaluated for this case study, Crash Frequency, Crash Rate, Equivalent Cost, and the HSCA. Results of Crash Frequency and Equivalent Cost were often in agreement, with the Equivalent Cost method being able to more precisely differentiate between locations with a similar number of fatal crashes but differing numbers of less severe crashes. Results from the Crash Rate method and Highway Safety Corridor Analysis method were sensitive to the range of values for the exposure measure. The tools perform two methods for counting crashes along a segment. The Sliding Window method would be very difficult to implement outside of a programming environment and the results would not be intuitive to interpret without the mapping capabilities included within the GIS platform.

CHAPTER 5. POSSIBLE CRASH COUNTERMEASURES FOR RITI COMMUNITIES: A SYNTHESIS

5.1. Overview and Introduction

A rough definition of a rural road is one that is outside of an urbanized area/city. It can be classified by the average daily traffic the road sees with a rural road being below a specific benchmark. This can result in some rural roads not fitting the description due to recreational attractions causing a rural road to see more traffic. Rural roads are more predominant in agricultural communities, low density/small population communities, low-income communities, and tribal communities. These roads, on average, are two lane roads with low lane width. Often roads have little to no signage or markings, i.e., centerline, edge line, or right of way signs. The absence of signs and road markings in combination with horizontal curves results in a large number of vehicle accidents.

Appropriate countermeasures are dependent upon the type of road, horizontal alignment, geographic location, and available resources. Roads are either paved or unpaved (earth and gravel) with each presenting its own set of unique challenges. Paved roads provide the advantage of being able to put additional information in the driver's field of vision through road markings that is unavailable to unpaved roads. They also provide better friction between the road and the vehicle's tire because of its better drainage properties.

The Federal Highway Administration (FHWA) has a program targeting crashes in rural areas, researching, developing and implementing countermeasures to focus on reducing rural roadway departures (FoRRRwD). The program has four main objectives: all public roads, proven countermeasures, using a systematic approach, and safety action plans. FoRRRwD wants to consider all rural public roads where rural roads are considered to be locally owned, off the state highway system (Federal Highway Administration, 2021).

There are three objectives for the FHWA's FoRRRwD countermeasures program. The first is to help drivers keep their vehicles in the lane. The second is to reduce the potential for crashes if a driver does end up leaving the lane, as in giving the driver resources to recover. The last is to reduce the severity of a crash should one occur. This is a last resort as the countermeasures are not foolproof. An overarching theme of the countermeasures is for them to be flexible and cost-effective. Flexible here is defined as being able to implement a countermeasure in multiple situations and on various road types. Cost-effective countermeasures are significant because local communities are usually limited by the financial aspect restricting what countermeasures are available to them (Federal Highway Administration, 2021).

The systematic approach is critical in determining possible locations to install countermeasures. Rural roads have roadway departures that change with each year making it difficult to decide where to implement a proven countermeasure. Using analysis tools, locations can be highlighted for having the highest risk of future crashes. There is some difficulty with this as rural road crashes often go unreported, and this systematic analysis requires crash and road data to determine where the highest risks are along a road (Federal Highway Administration, 2021).

5.2. Engineering Countermeasures

5.2.1. Markings

Most rural roads lack the presence of road markings. The simple presence of a centerline improves a driver's ability to maintain their line on what is most likely a two-lane road. This countermeasure is also the initial treatment for horizontal curves to help delineate the curve (Himes et al., 2017). Complementary to centerline markings are edge line markings. These define the edge of the roadway. This can help reduce vehicles drifting onto the shoulder, roadside, or off the paved road. Additionally, edge lines guide drivers at night when vision is impaired by oncoming headlights (Himes et al., 2017).

Raised pavement markers are used in supplement to or to replace centerlines or edge lines. These devices are small, typically raised devices that range from non-reflective to internally illuminated (Albee et al., 2016). Their design is dependent upon the climate there are being used in. For example, in colder climates where snow plays a factor, the pavement marker must be indented into the road surface with metal coverings which allows snowplows to remove the snow.

Profile pavement markings are an alternative to the raised pavement markings for either/both the centerline and edge lines (Albee et al., 2016). Thermoplastic is used as raised profile along the line. This is intended to improve the visibility of the line in nighttime condition to prevent the driver from drifting. The raised profile also generates a rumbling effect to alert the driver if drifting does occur.

Centerlines and edge lines may be supplemented with rumble strips to further prevent drivers from drifting off the road/across the centerline (Himes et al., 2017). This helps roadway departure crashes including head-on and run-off crashes. There are two types of rumble strips: milled and raised. Milled strips are implemented using a rotary milling machine creating an alternating groove. When the tires drop into this groove, both sound and vibration are generated through the vehicle alerting the driver that they are drifting off the road/across the centerline.

Raised rumble strips, commonly referred to rumble stripes, are primarily used in warmer climates where it is difficult to install milled rumble strips (Himes et al., 2017). They are similar in fashion to profile pavement markings where they can be created using plastic inserts within thermoplastic markings; however, they can also be installed using side-by-side pavement markers or rumble bars. Thermoplastic pavement markings also improve nighttime wet pavement visibility; however, their rumbling effect is limited.

5.2.2. Signage

Speed advisory markings in lane are countermeasures as the roadway approaches a horizontal curve. They are intended to be supplemental to curve warning signs with speed advisory plaque (Albee et al., 2016). Optical speed bars (speed reduction markings) are transverse stripes that a placed at both sides of the lane (Albee et al., 2016). The distance between them gradually decreases as the vehicle approaches the curve. This is intended to give the perception that the driver is going faster than they are, thus motivating them to slow down as they approach the curve.

Advance warning signs can also be installed to alert the driver to upcoming road conditions that may be unexpected. An advisory speed plaque is commonly placed under an advance warning sign for horizontal curves to advise motorists to reduce their speed (Albee et al., 2016). This is only an advised speed; it is not the legal speed limit for the curve. Some horizontal curves contain an intersection increasing the chances of an accident. Advance warning signs can be modified to include combination curve/intersection signs to alert the driver of possible oncoming/departing traffic.

Horizontal curves are often used in combination with vertical alignments, thus creating site line issues where the driver moving on an incline cannot see the upcoming curve. A proven countermeasure for this issue is the installation of Chevron alignment signs (Albee et al., 2016). These accentuate the curve and direct drivers through the horizontal curve. Chevron signs can define the direction of the curve and how urgent the curve is through their pattern, size, and placement. When a horizontal curve becomes sharp, near 90-degree angles, it may be appropriate to replace Chevron signs with one-directional large arrow signs (Albee et al., 2016).

To further gain motorists' attention, flashing beacons can be installed. These beacons are commonly used in combination with advance warning signs for upcoming horizontal curves (Albee et al., 2016). This countermeasure is not an initial treatment for a curve, it is resorted to when other countermeasures have been determined to be ineffective. Some flashing beacons are being used within dynamic curve warning systems. These systems use the beacons/messages that are triggered by a vehicle approaching a horizontal curve at a high speed (Albee et al., 2016). A common system includes flashing beacons, message sign, and speed measuring device that activates the system.

5.2.3. Roadway Improvements

Another approach to reducing the rural road departures is to target the contact between the tire and the pavement. Wet pavements will reduce the pavement friction and increase the possibility of skidding. Large amounts of water on roadway surfaces can cause hydroplaning; however, roadway departures are more commonly caused by small amounts of water reducing friction by 20 to 30 percent. High friction surface treatments (HFST) are a developing countermeasure that increases the friction on a specified segment of roadway, usually horizontal curves (Albee et al., 2016). A high-quality aggregate, calcined bauxite has been found to provide the most friction and skid resistance, is applied to high-crash areas to assist drivers' control in both dry and wet conditions.

Pavement grooving is another countermeasure to increase pavement friction by making horizontal and vertical cuts into the roadways surface, but this countermeasure is limited to concrete (Albee et al., 2016). Pavement grooving has been proven to be effective in reducing wet-weather crashes because it improves the drainage of the road. Negative effects of this countermeasure are vehicle noise, reduced driver comfort, and possible increased weathering of the road surface. This is a developing technology with new improvements being made to reduce the vehicle noise.

Another countermeasure to reduce roadway departures is to help the driver recover after drifting has occurred. Shoulder widening provides additional road width outside of the edge line (Albee et al., 2016). This treatment is predominantly used for horizontal curves because vehicles tend to use more lane width on the curve than straight sections. Widening the shoulder of the road provides more room to recover for the driver and is commonly used in combination with rumble strips and Safety Edge^{SM}. Safety Edge^{SM} is paving technique that improves pavement durability along with reducing crashes (Albee et al., 2016). The treatment must be applied when the road is being put down. It calls for shaping the edge of the road into a 30-degree wedge, and this allows the driver to make a controlled recovery after drifting off course. In practice, it is recommended to bring adjacent material/roadside vegetation even with pavement surface covering Safety Edge^{SM} after paving is complete.

Unpaved roads do not have the benefit of on road pavement markings thus making them more challenging especially on horizontal curves. Advance warning signs are still a possible counter measure for unpaved roads. A common countermeasure used for horizontal curves on unpaved roads are delineators (Albee et al., 2016). Delineators are retroflective devices that are mounted above the roadway surface and placed along the side of the road to demonstrate roadway alignment. These devices can be used for both paved and unpaved roads.

Superelevation of the road is a key geometric design element that can act as a countermeasure along horizontal curves (Albee et al., 2016). It is designed to assist acceleration through the curve, working with the friction between the pavement and road surface. It can be implemented for both paved and unpaved roads; however, it is difficult to maintain the optimal superelevation for unpaved roads.

5.2.4. Roadside Improvements

In an event when roadway departures cannot be avoided, a clear zone is desired on the roadside. A clear roadside is relatively flat and free of non-breakaway structures making it more likely for the driver to regain control of their vehicle. The clear zone is defined by AASHTO as “the unobstructed, traversable area provided beyond the edge of the through traveled way for the recovery of errant vehicles.” AASHTO provides values for the Design Clear Zone in AASHTO Roadside Design Guide along with values for the side slope (Albee et al., 2016). It states that slope of 0.25 and flatter is sufficient enough for a driver to regain control of their vehicle or stop. For slopes greater than 0.25, it is recommended that slope flattening be considered (AASHTO, 2012).

When other countermeasures such as markings, signing, shoulder adjustments, and roadside improvements are deemed insufficient in reducing roadway departures (or there is in adequate room) roadside barriers may be considered. The use of roadside barriers requires engineering judgement to evaluate the trade-offs. There are three types of barriers to be considered: cable, guardrail, and concreter.

Cable barriers are a flexible barrier made with wires supported between posts. Guardrails are a semi-rigid barrier that can be either a steel box or W-beam supported between posts (Albee et al., 2016). Concrete barriers are considered rigid barriers Typically, they are not used for rural roads.

5.3. Rural Road Challenges

The countermeasures previously described are intended to be low-cost solutions; however, on some rural roads there are additional costs that develop in order for the treatments to be implemented. For example, a flashing beacon or dynamic curve warning system are both highly effective countermeasures but are not cost effective in most rural areas because they require a power source. To install these would require power to be run to the location, and this is not only an installation cost, but it mandates a maintenance cost as well. Overall, many countermeasures that would be used for a normal road would financially be unreasonable on a rural road.

Rural roads also face difficulties from animals, both domesticated and wild. Deer crossings are a national issue causing approximately a billion dollars in damage each year along with some events taking human life. These crashes are usually caused by the instinct of the driver trying to avoid the deer and losing control of the vehicle. In areas where rural roads lie in agricultural communities, grazing cattle can wander on to the road. The usual countermeasure for this issue is to put up warning signs, for either situation, with a reference for distance added. Other countermeasures such as a driver activated whistle have been proven to be ineffective. Some agencies have been using roadside reflectors intended to stun the wildlife and keep them off the road at night. This treatment, however, is costly with unproven results.

5.4. Roadway Maintenance Practices Indirect Costs

Both road types, paved and unpaved, have indirect costs related maintenance. After a countermeasure is implemented, they need to be maintained to sustain their benefit. Rural roads are maintained in one of three ways, routine, periodic, and rehabilitation maintenance (Burningham and Stankevich, 2005). Routine maintenance consists of preserving the roads and weekly upkeep of roadsides. Periodic maintenance consists of regravelling unpaved roads and resealing paved roads. Rehabilitation maintenance consists of complete restoration of roads including structural restoration. Logistically, routine and periodic maintenance are less costly than rehabilitation. Though in local communities, the low usage of these rural roads makes the cost of maintenance to be perceived as outweighing the benefits.

The cost of maintenance is dependent upon the road conditions, location, weather, traffic volume, and method of choice along with other factors. Typical paved road maintenance includes grading, crack sealing, patching, edge repair, surface dressing, spot rehabilitation, overlay, and reconstruction (Burningham and Stankevich, 2005). Common unpaved road maintenance includes roadside clearing, grading, spot regravelling, regravelling shaping, rehabilitation, and upgrades.

Inclement weather can increase the need and frequency of maintenance, specifically upon unpaved roads because the gravel becomes eroded. Paved roads face less of a challenge because of their better drainage. The primary issue for unpaved roads is erosion or the deterioration of the unsealed surface (Burrow et al., 2019). In wet climates, unpaved roads face a significant amount of runoff and in large intensities it can cause the gravel surface to be carried by the flow resulting in it adding sediment to a watershed. On earth roads, the major challenge is the rain causing the sub-base to fail resulting in the road washing away.

There are four major types of erosion of unpaved roads: splash, sheet (inter-rill), rill, and gully erosion (Burrow et al., 2019). Splash erosion is caused by rainfall, which is where surface water erosion begins. The kinetic energy of the rain's impact dislodges the soil. Inter-rill erosion occurs if ponding begins, allowing surface flow to be on the road surface. It is associated with splash erosion because rain impact still has some effect because of the time gap from rain impact to the beginning of overland flow. Rill erosion is when sheet flow concentrates into small streams, such as ruts created by the wheel paths and winter tires. The size of the stream is directly related to traffic volume. Gully erosion is the result of not treating rill erosion, where the streams become wide and deep with the possibility of destroying the road.

In colder climates winter conditions create new maintenance challenges. Many unpaved roads use both salts and abrasive treatments when snow and ice cover the road. Abrasives, such as sand, must be used mindfully because they are not effective when they are mixed up in the snow and have little connection with the tires (Walker, 2005). Salts are intended to melt the ice which can create runoff an increase erosion.

CHAPTER 6. STUDY CONCLUSIONS AND RECOMMENDATIONS

This report describes a new set of Geographic Information System (GIS) tools that we created to conduct safety analyses. These new GIS tools can be used by state DOTs to document crash data and prioritize safety improvement projects. The tools perform Network Screening and segment screening and are the first step in the Roadway Safety Management Process (RSMP) outlined in the Highway Safety Manual (HSM). The developed tools are available through the Center for Safety Equity in Transportation (CSET) website and the USDOT's Bureau of Transportation Statistics Repository & Open Science Access Portal (ROSA-P).

After developing these new tools, we conducted two case studies to demonstrate how they can be used. The first case study was for screening intersections. Our analysis included all intersections on the Idaho State Highway System. In practice, the analysis would likely be done only for a subset of intersections, such as only for signalized intersections on urban arterials. We chose all intersections for illustration purposes. The result was a ranking of intersections that would most likely benefit from safety improvement efforts. We applied three performance measures to rank the intersections: Crash Frequency, Crash Rate, and Equivalent Cost.

The second case study was for screening roadway segments. Again, the entire Idaho State Highway System was included for illustration. The HSM describes two key methods for screening roadway segments: Simple Ranking and Sliding Window. Both methods are available in the new tools. This second case study demonstrates the advantage of the Sliding Window, which would be impractical to accomplish on a large scale without the assistance of our new GIS tools. The final part of the work conducted as part of this project is a synthesis to identify and document possible measures to reduce crashes for RITI communities in Idaho and throughout the northwest region.

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APPENDIX A: SEGMENT ANALYSIS WORKFLOW